national accelerator laboratory

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EXTRACTION FROM THE MAIN RING

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The extraction septum and channel have been described elsewhere (e.g., Proceedings of the 1971 Particle Accelerator Conference, p. 984). The only information required here is that of the electrostatic wire-septum and the Lambertson magnets.

Electrostatic wire-septum

wire diameter = 0.05 mm

wire spacing = 1.25 mm

septum location: 1.9 m after the first "4-ft" quad (QF') and 3.0 cm out from beam center-line ($\alpha_x = 0.4406$, $\beta_x = 96.78$ m, $\alpha_y = -0.2068$, $\beta_y = 27.24$ m, $x_p = 2.276$ m)

aperture = 1 cm(h) x 1.5 cm(v)

beam deflection = 0.2 mrad (two units) at 200 GeV

Lambertson magnet

location of entrance: 0.4 m after the beginning of "50 m" long drift ($\alpha_x = -.1940$, $\beta_x = 46.63$ m, $\alpha_y = 1.303$, $\beta_y = 121.40$ m, $x_p = 2.014$ m)

aperture = 1.5 cm(h) x 2.5 cm(v)

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Slow Extraction

1. Phase 1

Two bump magnets are installed at F46 (β = 95 m) and A17 at phase angle 1.016 x 2π apart. Each magnet can be pulsed at a maximum rate to kick 200-GeV beam 15 mrad/sec. (A new power supply is required to do this. With the present power supply the maximum rate is 3 mrad/sec.) At the septum, the phase angle from F46 is 0.196 x 2π, and the orbit displacement is

$$\sqrt{95\text{ m} \times 96.8\text{m}}\ \sin\,(0.196 \times 2\pi) = 90\text{ mm/mrad at F46.}$$

Therefore, the beam can be bumped across the septum at a maximum rate of 1.35 mm/msec or .028 mm/turn. Since the beam half width at the septum is ~3 mm (for emittance = 0.1π mm-mrad) the fastest extraction is ~2.2 msec or ~100 turns.

During this slow extraction all the beam will at some time hit the septum and is scattered into the extraction channel by the septum. The extraction efficiency is low (~80%) and the extracted beam quality poor.

The procedure of extraction using this scheme is the following: On the main ring magnet flat-top, first, move the beam as close as possible to the septum, either by rf or by reducing the bending magnet field if the rf structure in the beam is not desirable. [Since x_p is rather small at the septum location it is not possible to move the beam right next to the septum (~3 cm out) in this manner.] Then the bump magnets are pulsed at the desired rate and the beam is bumped onto the septum and scattered into the extraction channel by the wire septum.

2. Phase 2

A scatterer installed at phase angle $\frac{\pi}{2}$(odd integer) upstream of the septum and at a high-β location, scattering the beam into the channel will greatly improve the extraction efficiency and the quality of the extracted beam. Because of the momentum spread in the beam the dispersion x_p at the scatterer should be the same as x_p at the septum. The best location for the scatterer is in the wire-septum straight section in sector E at the exact symmetric position as the septum. The phase angle is then $\frac{\nu}{3} \times 2\pi \cong 27\frac{\pi}{2}$, and β and x_p at the scatterer are identical to those at the septum. In this case we should use two pairs of dc beam bump magnets turned on on the flat-top [The turn-on can be rather slow and can start on the later part of the ramp before the flat-top.] to move the beam next to the septum and the scatterer. A reliable beam-position monitor at the septum is essential. It is, however, not essential to know the exact position of the beam at the scatterer because the position of the scatterer will be adjusted to the beam. Then the beam is moved slowly outward by its half-width of 3 mm in the desired spilltime and in a controlled manner by either the rf or the bending-magnet field.

The scatterer should be a tungsten strip 0.1 mm x 1.6 mm in cross-section stretched vertically with the long cross-dimension (1.6 mm) along the beam and positioned to shadow the septum. Both the horizontal position of the scatterer and the tilt of its long dimension from the local beam direction should be adjusted empirically by optimizing the extraction efficiency, hence must be remotely adjustable to very good accuracy, say <0.05 mm in horizontal position and <1 mrad in tilt.

A 200-GeV proton going through 1.6 mm of tungsten receives an rms scattering angle of

$$\theta_{rms} = \frac{0.015 \text{ GeV/c}}{201 \text{ GeV/c}} \sqrt{\frac{1.6 \text{ mm}}{3.6 \text{ mm}}} = 0.05 \text{ mrad.}$$

The displacement of the particle from the beam center at the septum is about 100 mm/mrad at scatterer. At the start of extraction the septum aperture extends from 3 mm (beam edge) to 13 mm from the beam center which corresponds to scattering angles of -.03 mrad to -.13 mrad at the scatterer or $-\frac{3}{5}\theta_{rms}$ to $-\frac{13}{5}\theta_{rms}$. At the end of extraction when the beam half-width has been scraped down to zero the septum aperture extends from 0 mm to 10 mm corresponding to scattering angles of 0 to -0.1 mrad $= -2\theta_{rms}$.

The vertical aperture of the extraction channel lets through all beam scattered vertically within $\pm 3\theta_{rms}$. The extraction efficiency should be >95%. The full widths and angular spreads of the beam in the extraction channel are given below:

Horizontal-Beam Limited by Wire-Septum Aperture

Position	Δx (mm)	$\Delta x'$ (mrad)	Optical Characteristic	Physical Aperture (mm)
Wire septum	10.0	.0518	converging	10
Entrance to Lambertson magnet	6.06	.0479	converging	15
End of "50m" drift space	3.64	.0479	converging	35
First quad in extracted beam	2.51	.0479	converging	

Vertical-Beam Scattered within $\pm 3\theta_{rms} = \pm 0.15$ mrad

Position	Δy (mm)	$\Delta x'$ (mrad)	Optical Characteristic	Physical Aperture (mm)
Wire septum	11.4	.143	diverging	15
Entrance to Lambertson magnet	17.5	.320	converging	25
End of "50m" drift space	5.19	.320	diverging	15

3. Phase 3

Eventually we could use the third integral resonance, say $\nu_x = 20\frac{1}{3}$ to step the beam across the septum into the extraction channel. This process has been studied in detail by Symon (FN-130, 134, 140, 144), Teng (TM-271) and Ohnuma (Proceedings of 1971 Particle Accelerator Conference, p. 1015) and will not be reelaborated here. This scheme is delicate and exacting but should give the best extraction efficiency (~99%) and extracted beam quality.

Fast (One-Turn) Extraction

The beam can be kicked rapidly across the septum into the extraction channel by a fast kicker located, again, at $\frac{\pi}{2}$(odd integer) phase advance from the septum. The best location for the fast kicker is, again, in the wire-septum straight section in sector F. To displace the beam its full width of 7 mm (betatron width = 2 x 3 mm, momentum width = 2 x 0.5 mm for $\frac{\Delta p}{p} = \pm 2 \times 10^{-4}$ debunched) plus an allowance of 1 mm at the septum the kick angle required is 0.08 mrad. The present MR injection kicker (or booster extraction kicker) is 1 m long per module, and can kick the 8-GeV beam $\frac{1}{3} - \frac{1}{2}$ mrad per module or, equivalent, for 200-GeV beam

$$0.015 - 0.022 \text{ mrad per module.}$$

Therefore, we need

$$4 - 6 \text{ modules}$$

which can easily be fitted into the 9.3 m long wire-septum straight section. The rise time of

$$50 - 100 \text{ nsec}$$

is adequate if the kickers are timed to fire at a gap in the MR beam. The only modification required is to convert the present vertical kicker into a horizontal kicker. The extraction efficiency and the quality of the extracted beam should be very good. Since the whole beam is kicked into the extraction channel, up to the end of the "50 m" the optical characteristics of the beam in the channel are identical to those of the beam in the MR.

The procedure of fast extraction is as follows: On the magnet flat-top (or not-so-flat-top) debunch the beam to reduce $\frac{\Delta p}{p}$ by turning the rf off adiabatically, then move the beam out next to the septum by a pair of slow beam bump magnets. When the beam gets next to the septum [Again, a good position monitor at the septum is important.] the fast kickers are, then, fired to kick the beam into the extraction channel. The firing of the kickers should preferably be timed to a gap in the beam. Furthermore, if the kickers can be turned off as fast as they are turned on we can extract any fraction of the full turn of beam.